Preprint
UCRL-JC-150831

Simulating Ocean Fertilization: Effectiveness and Unintended Consequences

K. Calderia

This article was submitted to the National Academy of Engineering, Kyoto, Japan, April 22, 2002

November 3, 2002

Simulating Ocean Fertilization:
Effectiveness and Unintended Consequences

Ken Caldeira

Numerical simulation can throw some fresh light on the idea of ocean fertil

Analysis of the IS92A IPCC scenario shows that, by the end of this century, stabilize climate at only a two-degree warming, even if climate sensitivity end of the acceptable range, approximately 75 percent of all power producti need to come from carbon emission-free sources. If climate sensitivity is a of the accepted range, nearly all of our energy would need to come from car emission sources to hold global climate to a two-degree warming. We can per the same sort of calculation for a range of climate sensitivities and a ran warmings. To achieve stabilization at 2¡C for a mid-range climate sensitivi have to add approximately one gigawatt of carbon-free primary power per da somewhere in the world.

The magnitude of this problem is enormous. There is not going to be a single As other speakers have suggested, we need to work on diminishing energy dem need to work on sequestration and we need to develop non-fossil sources of

Our speakers today have already discussed geologic storage and ocean storag direct injection. Land biosphere storage has also been suggested, although be limited in its amounts and effectiveness, as well as limited by land ava have proposed geo-chemical techniques, such as accelerating silicate or car weathering.

One problem with putting CO_2 into the ocean is that nobody thinks putting CO ocean is good for the ocean. We may want to do it if it turns out that the environmental consequences of putting carbon in the ocean are significantly the adverse consequences of putting it in the ocean. It only makes sense if adverse consequences of releasing CO_2 into the environment

As Peter Brewer pointed out, right now we re already putting two gigatons the ocean each year. That works out to something like five kilograms per da citizen. At present, we are putting carbon into the atmosphere, which may c significant climate change. But eventually, the ocean will absorb about 80 carbon released to the atmosphere. The idea of ocean sequestration is to put the ocean deliberately and directly in an effort to avoid global warming. potential of some adverse impacts on the marine environment, but we at leas avoid most of the climate change.

I think the recognition that we re already sequestering carbon in the ocean is very important. The work that Peter Brewer and Jim Barry are doing on th effects of CO_2 on organisms in the ocean is some of the most important work today. If it turns out that that s an important concern, it is essential to admitting CO_2 to the atmosphere.

I want to talk mostly about simulations for ocean fertilization, focusing o options. Other options have been proposed--for instance, adding chemicals s

nitrate and phosphates to the oceans, as well as a set of inorganic strate
the carbonate dissolution idea.

What s the basic idea behind ocean fertilization? As Peter Brewer pointed exchange between the upper ocean and the deep ocean; the timing of the exch on the order of several centuries. The upper, mixed layer equilibrates with atmosphere, roughly on a time scale of a year or so. The basic idea of iron fertilization is to add iron to the upper ocean, stimulating increased biolo increased photosynthetic activity and generating more organic carbon--remov the surface. Some of this organic carbon then sinks into the deep ocean. Th fertilization is to remove carbon from the surface ocean, fix the CO_2 as or and then sink it into the deep ocean. That s just a mostly gravitational sir particles. Because CO_2 has come from the surface ocean, the partial pressur that surface ocean box has been decreased. That drives a compensating flux from the atmosphere into the ocean, drawing more CO_2 out of the atmosphere.

If this is as far as it would go, we d have a permanent sequestration and would be fine. But, time moves on. When this organic carbon gets into the d is oxidized back to CO_2. This CO_2 can get mixed back up to the surface ocear can out-gas back to the atmosphere; then it can actually gas back into the the atmosphere, and so on. The CO_2 that went into the ocean over here someti out-gas back to the ocean. The ocean serves as a temporary storage system. about the concept of temporary storage a little later.

A number of people have done idealized simulations using general circulatior also schematic models on this question. Their simulations suggest that afte southern ocean for a century, it would be possible to store carbon in a ra gigatons to 250 gigatons. I worked on a highly idealized simulated fertiliz with the premise that, working on everything south of 30 degrees, we could micronutrients to the ocean to completely deplete the surface macronutrient phosphate. This was done using the Los Alamos POP model. One early discover this simulation was that, after only three years, some CO_2 had already begu back into the atmosphere. If we compared 3 years, 30 years, and 300 years, that previously sequestered carbon was leaking back out over much of the r ocean. By 300 years, there was significant leakage in the tropics. There a for that leakage. One is that carbon placed in the deep ocean eventually mi the surface. Another reason is that, along with this organic carbon sent d deep ocean, we also sent down nutrients, increasing the deep-ocean nutrient the expense of the surface ocean. Biological productivity in other parts of began to diminish.

In this fertilization simulation, approximately 375 additional gigatons of in the ocean over a course of 400 years. On this time scale, the storage is of about one gigaton per year. The net flux starts out close to eight gigat About a century in, there is about one gigaton. By 400 years, there is abou gigaton.

My sense is that these are upper boundary numbers. A real-life effort woul fertilize the entire ocean south of 30 degrees. The areas that are fertili probably not perform up to maximum possibilities. It is important to underst fertilization, insofar as it works and is environmentally and politically a these things that might become part of the portfolio of responses. It s not itself to solve the problem.

Earlier I mentioned that as we continue fertilizing, we start moving phosph away from the upper ocean. Thus, the effectiveness of the iron fertilizati over time as the surface ocean runs out of macronutrients. In addition, the carbon to the added exports from the surface ocean to the deep ocean decre time, because previously stored carbon is leaking back into the atmosphere.

What is the residence time of carbon in the ocean? The ocean likes to trans along surfaces of constant density. The density is controlled by temperatur surfaces outcrop at the colder Poles. There are surfaces in the deep ocean well ventilated. Even though more organic carbon is being transported, more retained down there; whereas in other parts of the ocean, when CO_2 is depo amount slips back into the atmosphere much more quickly.

We can ask how ocean carbon sequestration changes allowable emissions by calculating the net pros and values as functions of a discount rate and ass price trajectory. With a zero discount rate, there is no time preference, a no point doing ocean fertilization because you re not discounting future va should look at the discount rate minus the emission cost--because we could percent discount rate but the cost of carbon emissions could rise at the ra so that, once again, we gain nothing. Taking the range of discount rates th typically in business, we would have to initially sequester three gigatons at .33, in order to get one gigaton of carbon s worth of sequestration valu words, we take roughly a factor three for the fact that this is not a perm sequestration.

In one simulation, organic carbon that sank into the deep ocean oxidized, cc ambient dissolved oxygen in the water column. I found that after 300 years, formed in the model ocean that had severe oxygen depletion--suggesting poter to oxygen-breathing organisms.

Green Sea Ventures estimates that the cost of iron fertilization would be $ ton. But because it is a temporary sequestration, we must also consider tha necessary to multiply the cost by an approximate factor of three to get the value. Macronutrient strategies are considerably more expensive. There are suggestions that ships could just dribble along some iron to compensate for CO_2 admitted by ships.

A model is helpful for trying to understand the conceptual situation, but a better than the basic knowledge that went into it. There are many, many unk of this. We still don t know to what extent adding nutrients to the surfac stimulate marine production of organic carbon and how that varies from envi environment. Although, we re making progress in that area, we re not sure, carbon production is increased, what fraction of that will sink to the dee organic carbon that sinks to the deep ocean, some carbon can mix up from be some CO_2 can come from the top. A deficit in the surface ocean may also be n Exactly how much a flux of CO_2 from the atmosphere will compensate for this flux is also unclear, as it is unclear how deep the CO_2 will sink in differ before it is oxidized. Once it is oxidized, it is also unclear exactly how down there before it cycles back up to the surface. There are also some di

although I think I know the right answer, for how to properly account for
gas seen in de-gassing situation.

If all the CO_2 that has been sequestered eventually leaks back into the atmo
all we are really doing is just time-shifting emissions. We re putting it in
leaking out 100 years from now, or 200 years from now. How can we say what
value of time-shifting an emission is? It s not simply economics. One reason
emissions is to make time to invent new, carbon-emission-free energy techno
Reducing emissions, in the short term, might be worth doing in anticipation
technologies coming on line in the long term.

This work supported by the Ocean Carbon Sequestration Research Program of th
Office of Biological and Environmental Research. This work was performed un
auspices of the U.S. Department of Energy by the University of California,
Livermore National Laboratory under contract No. W-7405-Eng-48.